TRANSPORTATION OPTIMIZATION MODEL OF PALM OIL PRODUCTS FOR NORTHERN PENINSULAR MALAYSIA

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TRANSPORTATION OPTIMIZATION MODEL OF PALM OIL PRODUCTS FOR NORTHERN PENINSULAR MALAYSIA

by

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Peace and Blessings be Upon His Beloved Prophet

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LIST OF ACRONYMS

Environmental

CAAA	- Clean Air Act Amendments
CH4	- Methane
CO	- Carbon Monoxide
CO2	- Carbon Dioxide
EPA	- Environment Protection Agency
GHC	- Greenhouse Gases
IEA	- International Energy Agency
NAFTA	- North American Free Trade Agreement
NO x	- Nitrogen Oxides
O_3	- Ozone
PM	- Particulate Matter
SO2	- Sulfur Dioxide
VMT	- Vehicle Mile of Travel

Palm Oil Industry

AAR	- Applied Agriculture Research
CPO	- Crude Palm Oil
CPKO	- Crude Palm Kernel Oil
EFB	- Empty Fruit Bunch
FFB	- Fresh Fruit Bunch
FELCRA	- Federal Land Reclamation Authority
FELDA	- Federal Land Development Authority
FRIM	- Forest Institute of Malaysia
MPOB	- Malaysian Palm Oil Board
MMPBB	- Massachusetts Institute of Technology Biotechnology Partnership Programme
NBD	- Neutralized Bleached and Deodorized
PK	- Palm Kernel
PORIM	- Palm Oil Research Institute of Malaysia
RBD	- Refined Bleached and Deodorized
RISDA	- Rubber Smallholders Development Authority

Transportation Industry

AMH	- Association of Malaysian Hauliers
ATA	- American Trucking Association
CHAM	- Container Hualiers Association of Malaysia
CSCMP	- Council of Supply Chain Management Professionals
FAF	- Fuel Adjustment Factor
GVW	- Gross Vehicle Weight
IMO	- International Maritime Organization
ISO	- International Organization for Standardization
LTL	- Less-than-truckload
TEU	- Twenty foot Equivalent Unit
TL	- Truckload
3PL	- Third Party Logistics

Transportation Operations Research

DC	- Distribution Centers
DP	- Dynamic Programming
FCTP	- Fixed Charged Transportation Problem
FCLM	- Flow Capturing Location-Allocation Model
GA	- Genetic Algorithm
IP	- Integer Programming
JIT	- Just In Time
LP	- Linear Programming
LRP	- Location Routing Problem
MCLP	- Maximum Covering Location Problem
MILP	- Mixed Integer Linear Programming
MIP	- Mixed Integer Programming
NP-Hard	- Non-deterministic Polynomial-time Hard
O-D	- Origin Destination
SPLP	- Simple Plant Location Problem
TSP	- Travel Salesman Problem
UFLP	- Uncapacitated Facility Location Problem
VRP	- Vehicle Routing Problem

MODEL PENGOPTIMUMAN PENGANGKUTAN BAGI PRODUK BAHAN MINYAK SAWIT UTARA SEMENANJUNG MALAYSIA

ABSTRAK

Dalam tesis ini, model matematik pemprograman integer telah dibangunkan untuk menyelesaikan masalah pengangkutan minyak sawit mentah dan isirong sawit di Utara Semenanjung Malaysia. Produk-produk ini berasal dari kilang sawit dan dihantar ke destinasi masing-masing, kilang penapis and kilang pelumat isirong. Kedua-dua masalah pengangkutan telah diselesai untuk mendapatkan pengagihan optimum bagi kilang ke penapis dan kilang ke pelumat menggunakan fungsi objektif meminimumkan jarak perjalanan. Kedua-dua penyelesaian memberikan jawapan pengagihan yang sama sebab pengeluaran minyak sawit mentah dan isirong adalah berkadar, untuk tiap-tiap produk kapasiti lori adalah sama, dan penapis dan pelumat terletak pada lokasi yang sama. Kajian telah diteruskan untuk melihat masalah lokasi kilang penapis, kilang pelumat, dan satu cadangan kilang kertas yang menggunakan hampas tandan sawit sebagai bahan mentah. Model pemprograman integer juga ditulis dan diselesaikan bagi pilihan lokasi pusat yang berpotensi, menggunakan jarak optima terdekat sebagai criteria pilihan. Lokasi paling sesuai bagi ketiga-tiga kilang penapis adalah Perai, Bagan Serai dan Terong, dan bagi kilang pelumat lokasi terbaik adalah Perai, Kuala Kurau dan Terong. Kedua-dua penyelesaian tidak sama kerana kapasiti memproses setiap individu kilang-kilang penapis dan pelumat adalah berbeza. Bagi cadangan kilang kertas, tempat yang paling tengah ia patut dibina adalah Bagan Serai. Penilaian alam sekitar pencemaran udara telah dibuat untuk karbon dioksida dan jirim habuk yang keluar dari asap lori hasil dari pembakaran minyak fosil kerja-kerja pengangkutan telah juga dijalankan.

TRANSPORTATION OPTIMIZATION MODEL OF PALM OIL PRODUCTS FOR NORTHERN PENINSULAR MALAYSIA

ABSTRACT

In this thesis, integer mathematical programming models were developed to solve the crude palm oil (CPO) and the palm kernel (PK) transportation problems for northern peninsular Malaysia. These products from the mills were sent to their respective destinations, the refineries and the crushers. The two transportation problems were solved to get the mills-to-refineries and mill-to-crushers optimal assignments using distance minimization as the objective function. The solutions revealed similar mills-to-refineries and mills-to-crushers assignments because CPO and PK are proportionate in quantity, truck capacities are homogeneous for each product, and refineries and crushers are located at identical locations. The research was then extended to look into the location problem of the refineries, the crushers, and a proposed pulp manufacturing facility that use empty fruit bunch as the raw material. Similar integer programming models were written and solved at selective choice of central potential sites, using optimal distance minimization as the selection criteria. The preferred locations for the three refineries are Perai, Bagan Serai and Terong, while for the crushers the best sites are Perai, Kuala Kurau and Terong. The two solutions are not the same due to the different individual processing capacities of the refineries and the crushers. As for the site of a proposed pulp manufacturing facility the most central location is Bagan Serai. Environmental air pollution assessments were conducted on the amount of carbon dioxide and particulate matter that were emitted in the air as a result of fossil fuel burnt from trucks doing the transportation job.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The oil palm, *Elaeis guineensis*, originates from West Africa [5]. Its commercial value lies in the oil obtained from the mesocarp of the fruit and the kernel of the nut. The oil extracted has cooking applications such as cooking oil, margarine and shortening, as well as non-food usages like soaps, detergents, lubricants and cosmetics [69]. Up from where the fruit tree is grown, it travels and passes through various processes, until it reaches down to where it is finally consumed.

The palm fruit oil is consumed worldwide in more than 100 countries. In some parts of the world, it is still consumed in its unrefined state, as an ingredient of traditional dishes, where it contributes its characteristic golden red color and unique flavor. However, to most users, palm oil is more familiar as a refined vegetable oil product, incorporated in their everyday food. The food everyone consumes everyday, such as baked goods, instant noodles, baby formula, cake mixes, breakfast bars, potato chips, crackers and even french-fries are likely made using palm oil. Of the oils and fat market, palm oil might serve best in meeting today’s consumers’ criteria. It is healthy, abundantly available, relatively inexpensive, and technically suitable for most food products. Perhaps this is why palm oil has become the largest internationally traded vegetable oil in the world proving its acceptance in the global market [88].

About 80% of palm oil currently goes into food applications and the remaining 20% goes into the non-food applications [5]. The non-food uses of palm oil and palm kernel oil can be classified into two categories; using the oils directly or by processing them into oleochemicals. Products produced using the oils directly include soaps, plastics and drilling mud. Products produced from the oleochemical route include candles, lotions, body oils, shampoos, skin care products, and cleaning products. Latest technologies has successfully created full range of skincare, body care, toiletries, cosmetics, candles and soap products that are made from palm oil and natural ingredients that do not contain petrochemicals and animal extracts which are completely biodegradable [87].

The red palm oil is super-healthy since it is free from cholesterol and trans-fat. The red palm oil is rich source in phytonutrients, such as vitamin-E and other carotenoids, which act as a super-antioxidant that is associated with reducing the risk of certain types of cancer. Recent studies have found other health benefits of palm oil, some of which are reduction in the incidence of arteriousclerosis (hardening of the arteries which can result in heart problems), reduction in blood cholesterol levels, reduction in blood clotting preventing heart attacks and strokes, and the inhibition of the growth of breast cancer cells [87].

Palm oil is not only an important food for the world, but it has become a source for the much awaited and urgently needed - the environmentally clean and renewable fuel, the bio fuel. Palm diesel, a renewable fuel derived from palm oil, has been established as a diesel substitute. With the announcement of the National Biofuel Policy by the government in 2005, the use of palm oil has moved to another dimension; the creation of environmental friendly and renewable energy called biodiesel. The announcement basically entails the strategy for bio-diesel fuel blend of 5% processed palm oil with 95% petroleum diesel [86]. With the current global trend towards renewable fuels, Malaysia has the edge over other nations since the production technology for palm diesel is already in place and the raw material, palm oil, plentiful in this country.

The Netherlands has opened yet a new usage for palm oil; the generation of green electricity. Raw palm oil or the crude palm oil (CPO) will be used as the primary fuel for the generation of electricity. Now, about 400,000 tonnes of CPO is imported by Dutch power plants for this power generation purpose. Based on 2005 estimates, the use of palm oil for electrical power generation could grow one or two million tonnes in the coming two to three years in Northwestern Europe [40].

The first commercial oil palm estate in Malaysia was established in 1917 in the state of Selangor. The cultivation of oil palm rapidly increased in the beginning of the sixties under the government's agricultural diversification programme, which was to reduce the countries economic dependence on rubber and tin. Later in the 1960s, the government introduced the land settlement scheme for planting palm oil as a strategy towards the utilization of available land in the less developed areas and at the same time increasing the rural population income, eradicating poverty and achieving greater equality in the distribution of income by mobilizing large numbers of the rural poor population to the more productive areas of those schemes. The growth of this industry has been very substantial since then. The total oil palm planted area reached 500,000 hectares in 1974 and doubled to become 1 million in 1980. Ten years later, in 1990 total hectares reached the two million mark. The total again doubled in the year 2005 to reach the four million hectares. Currently there is a total of 4.2 million hectares of land planted with oil palm [70].

Areas planted with oil palm can be categorized by the organization that manage the land. They are the private estates, government schemes and smallholders. The total hectares owned by private estates amounts to 2.5 million, which is 59% of the total area. Some of the big names in private estates are Guthrie, Sime Darby, Golden Hope and IOI Corporation. The government schemes, which comprise of Federal Land Development Authority (FELDA), Federal Land Reclamation Authority (FELCRA), Rubber Industry Smallholders Development Authority (RISDA) and state schemes, manage 1.2 million hectares or 30% of oil palm planted area. FELDA being the largest among the government schemes manages nearly 700,000 hectares or 16% of the total planted area. The remaining 11% belong to the smallholders, the area of which is less than 455,000 hectares [63]. Surveys have estimated the number of smallholders in Malaysia as 88,000, thus giving the average holding size of 5.2 hectares [69].

In 2006 with the export of palm oil and its related products amounting to 20.2 million tonnes and the income generated was RM31.9 billion [69]. For the last five years there has been a steady increase in the income generated from palm oil export. Although in terms of volume, export has always been on the increase, there was a slight decline in palm oil revenue in the year 2005 compared to the year before. This was due to the decline in the price of the commodity for that year. Malaysia's leading export destinations for palm oil for 2006 were China (RM5.82 billion), the Netherlands

(RM2.97 billion), U.S. (RM1.7 billion) and Pakistan (RM1.52 billion). Regional wise, major destinations for the Malaysian palm oil and its related products are East Asia (RM9.2 billion), European Union (RM5.9 billion), West Asia (RM3.8 billion), Middle East (RM2.8 billion), ASEAN (RM2.4 billion), Africa (RM2.5 billion), North America (RM2.3 billion) and Latin America (RM0.5 billion) [69].

The highest area under the cultivation oil palm is in the state of Sabah with more than 1.2 million hectares. This is almost thirty percent of the total area planted under oil palm in Malaysia. The next highest state with oil palm cultivation is Johore, which has almost 700,000 hectares. The third highest oil palm growing state is Pahang with more than 600,000 hectares, next comes Sarawak with 591,000 hectares, followed by Perak with 348,000 hectares. The states with more than 100,000 hectares are Terengganu, Negeri Sembilan and Selangor, while Kelantan, Kedah and Melaka cultivate at ranges between 100,000 and 50,000 hectares. The states with smallest hectares are Pulau Pinang (14,000 hectares) and Perlis (258 hectares) [69].

On the nation wide scenario, oil palm grown in 4.2 million hectares of land, produced almost 80 million tonnes of fresh fruit bunch (FFB) per year, which is then processed by 397 mills, producing 15.9 million tonnes of CPO, 4.1 million tonnes of palm kernel (PK) and leaving 18.32 million tonnes of empty fruit bunch (EFB). 51 refineries did the refinement of the CPO to yield processed palm oil. Some selected processed palm oil, are crude palm stearin, crude palm olein, RBD palm oil, RBD palm olein, RBD palm stearin, palm fatty acid distillate and cooking oil. In 2006 total production of these selected processed palm oil was 26.5 million tonnes. The 4.1 million tonnes of PK is taken to 38 crushers, and the crude palm kernel oil (CPKO) extracted is 1.3 million tonnes. The 18.32 million tonnes of EFB, now referred to as biomass, are largely taken back to the plantations to mulch as fertilizers. But, technology has permitted and infrastructure is being built to convert EFB into paper.

Palm fruits are harvested in the form of FFB, which must be sent immediately to the mills for processing. This immediate processing requires the mills to be located within the vicinity of the plantation area. To date Malaysia has 395 operational mills with the total approved capacity 84 million tonnes of FFB. Given a total processed FFB of 79.66 million tonnes a year, the average processing tonnage of the fruit per mill is more than 200,000. Mills are located all over Malaysia except Perlis, with the highest number in the East Malaysian state of Sabah, all together 112 in operation and 7 under construction, giving a total capacity of 28 million tonnes of FFB per year. Pahang is the second highest with 97, with accumulated capacity of 14.5 million tonnes FFB per year. Johor comes next with 67 mills but with higher capacity than Pahang, 15.8 million tonnes of FFB per year. The fourth highest number of mills is in the state of Perak (43 mills, capacity 8.7 million tonnes). As the highest number of mills is in East Malaysian state, the fifth highest is also from this part of the country, the state of Sarawak, with operating mills of 36 and 8 under construction, the combined potential capacity of 9 million tonnes. Selangor comes next with 21 mills, capacity of 3.5 million tonnes. Other states with mills less than twenty are Negeri Sembilan 15, Terengganu 12, Kelantan 10, Kedah 6, Pulau Pinang and Melaka each with 3 mills in operation [69].

There are 48 operational refineries in Malaysia with the total approved processing capacity of 17.3 million tonnes of CPO. Assuming all the CPO production of 15.88 million tonnes for the year get refined, the average refining activity was 333,000 tonnes per refinery per year or 900 tonnes per day. This average can be considered as low because recently built refineries are of capacities between 2,500 and 3,000 tonnes per day or 1 million tonnes per year. Refineries existed only in few states in Malaysia; Johor has the highest number of operational refineries, 17 altogether, with processing capacity of 6.6 million tonnes per year, followed by Sabah with 11 in operation and 8 under construction and their total potential annual capacity going to be 9.0 million tonnes. Selangor has 10 operational refineries with 2.5 million tonnes capacity. Other states with refineries are Perak (4), Sarawak (4) and Pulau Pinang (3) [69].

Crushers are the plants that do the extraction of the palm kernel oil. There are altogether 41 in Malaysia distributed in 8 states. Johore has the most number of crushers – 11 with capacity amounting to 1.2 million tonnes of palm kernel a year. To date the tonnage of palm kernel crushed in the state of Johor in a year is nearly 1.1 million tonnes. Second is Selangor and Sabah with 9 crushers each. Perak is next in the list with 4. Lastly, the states of Negeri Sembilan, Pahang, Pulau Pinang and Sarawak, each has 2 crushers. The two Eastern States of Sabah and Sarawak have the potential processing capacity of 1.7 million tonnes of palm kernel per year, and they actually crushed 1.5 million tonnes for the year 2006 [69].

Oleochemical plants processed palm oil and its derivatives, and palm kernel oil to produce basically fatty acids, fatty alcohols, methyl esters and glycerine which are used in the manufacturing of soaps/detergents/surfactants, rubber and plastics, paper, lubricants, personal care products (toiletries and cosmetics), textile auxiliaries, paints and pharmaceuticals. In total there are 18 oleochemical plants in operation in Malaysia, distributed in only 5 states. Johor has 7, the highest compared to other states. Other states comprise of Selangor 5, Pulau Pinang 4, and Pahang and Perak each with one [69].

Since processed palm oil is exported by the use of ship tankers, it made sense that the refineries are located at the ports. Export of palm oil and its related products are through the available ports in West and East Malaysia, such as Penang Port, Lumut Port in Perak, Port Kelang in Selangor, Pasir Gudang in Johor, Kuantan Port in Pahang, Kuching Port, Bintulu Port, Miri Port and Sabah Port. Penang port has a dedicated vegetable oil tanker pier just for handling the export of palm oil. The berth that pumps palm oil into ocean tankers is linked via overhead pipelines to facilitate direct loading and discharging of the edible oil to privately owned onshore storage tank farms. Available tanks are 92 in number with total capacity 114,200 tonnes. Lumut port is the deepest port in Malaysia with water depth span of 20 meters. With the added 500,000 tonnes capacity refinery linked to it by pipeline, and situated on a 342 hectare Lumut industrial park, it has the potential of becoming a major port for exporting palm oil. Liquid bulk cargo is handled at both Northport and Westport in Port Klang. Klang port management has 780 meters of berth length and Westport with 1.05 kilometers berth length, both of which handled liquid throughput, which is mostly petroleum. But their total palm oil export throughput is in the range of 2 million tonnes per year. Johor port is strategically located at the southern tip of peninsular Malaysia. It provides dedicated berths and facilities to handle palm oil, petroleum and petrochemical products as well as dry bulk and general cargo. 45% of its activities is the handling of liquid bulk, primarily the palm oil and petroleum. More than 4 million tonnes of palm oil is exported through this port in a year. One of the most active private companies that do the handling of palm oil export is Felda-Johor Bulkers, it has 280 tanks with a total storage capacity of 367,350 tonnes. Kuantan port is located on the central eastern coast of peninsular Malaysia, it aspires to become a regional hub on petrochemicals. Currently, 17% of what goes through the port is palm oil. Three berths with the total length of more than 600 meters are dedicated to palm oil. There are eight ports under the management of the Sabah Ports Sdn Bhd, but those that handle palm oil are Sandakan port, Lahad Datu port and Kunak port. Among those, Kunak is the port that handles mostly palm oil [71].

At the micro level harvested FFB is loaded onto from small 5-tonnes lories to 25-tonnes open trailers to be transported to the mills. A mill with an approved production capacity 216,000 tonnes FFB per year, for example, can process 45 tonnes per hour. This mill, during high crop season receives about 400 tonnes of FFB daily, which converts into 26 lorry trips each with 15 tonnes unloading the fruits into the mill.

The mills processed the FFB to extract the CPO and the by-product of this process is the palm kernel (PK). The CPO then gets transported to the refineries for further processing and the PK to the crushers for the palm kernel oil to be extracted. The output from the refineries are mostly the RBD (Refined Bleached and Deodorized) palm olein or commonly known as the cooking oil.

A mill, which receives 400 tonnes of FFB daily, produces about 170 tonnes of CPO. Some private mills do have their own tanker lorries, but the capacities of these lorries are rather small, something between 15 to 25 tonnes. So, if the mill uses only the 25 tonnes lorries, we expect to see some 8 lorries loaded with CPO leaving the mill to the refineries in a day.

As for the PK, about 40 tonnes are gathered daily. Usually the PK is not transported out daily because the PK do not go bad upon storage at room temperature, unlike the CPO which need to be processed immediately. The PK usually gets loaded in 40 feet open trailer, which can carry some 30 tonnes of the byproduct. If the PK is accumulated for 3 days then we can see 4 such trailers leaving the mill for the crushers the next day.

Composition chart in the palm oil production showed that the percentage of empty fruit bunch (EFB) is 23% of the FFB. Using this ratio and total available FFB of 79.66 million tones, a total of 18.32 million tonnes of EFB is produced. EFB represent only 9% of the total renewable biomass, which include trunks, fronts, shells and palm press (pericarp) fibre. Most of the EFB are taken back to the plantation to mulch as organic fertilizers. Some are burnt onsite with pericarp fibres and empty shells to produce industrial steam and electricity.

If the FFB is converted into pulp, Malaysia has the potential to produce millions of tonnes of pulp per year from FFB alone. Five tonnes of EFB could produce a tonne of pulp. Assuming 50% of the EFB is available for pulp production, Malaysia can produce

1.83 million tonnes of pulp a year. Based on the current pulp price of around US$500 a tonne [114], the value could be around US$0.915 billion a year.

Recent increases in the crude petroleum prices have great effect on CPO prices in the last few months when this thesis was written. When Malaysia announces it will start mass production of a palm oil-based biodiesel in 2008, the CPO prices have been closely tracking movements in the oil market. Tracing the price back from December 2003 when it was MR1800 per tonnes, it went down further a year later to RM1400. The price basically maintained till the end of 2005. Then it went up a little to RM2000 towards the end of 2006. The year 2007 saw some all time record for crude palm oil prices. In April the record highest till that time was RM2300, and still a record highest was in June when it rose to RM2700. The RM3000 mark was reached in November 2007. Astonishingly, the all time highest was in January 2008 when it reached the RM4300 level. At the time when this thesis was being submitted the price was around RM3300.

In this thesis, the transportation problem for an oil palm product, a byproduct and a waste product will be discussed. Together with transportation, the location issues of the facilities that processed those commodities will be addressed. This initial chapter starts with the introduction to the palm oil industry in Malaysia in general. Next, the local research activities and literature review on some of the transportation and location topics will be discussed. One section is also dedicated for the discussion of the overall transportation that relates to palm oil products. In the last two sections that follow the statement of the problem and research objectives are described. As for the rest of the chapters, the organization is as follows:

Chapter 2 discusses the concept of transportation, and then presents a brief introduction to container and tanker transportation. Some issues in local container transportation were also discussed. Some mention concerning topics such as third party logistics, collaborative logistics and supply chain were added. The next section discusses aspects of transportation in the agriculture, followed by a discussion on the effect of transportation to the environment. A presentation of location and vehicle routing issues is dealt in the next section. The chapter ends with a section, which specifically deal with the environmental impact on trucking.

Chapter 3 begins with the discussion on modeling concepts. This chapter focuses on the development and the derivation of the proposed models. Together with the model data collection for all the parameters of the model are included (yearly tonnage of the three products, processing capacities of refineries, crushers and paper making mill, and distance between locations), assumptions and solution approaches will also be discussed.

Chapter 4 discusses the application of the proposed models in solving the transportation and location problems stated in chapter 1. Various transportation optimal solutions were compared with one another to find the best locations for the facilities. Sections in this chapter are arranged in this order; introduction, input parameters, mill-refineries assignment, refineries location problem, mill-crushers assignment, crushers location problem, and pulp mill location problem.

Chapter 5 gives the overall conclusion for the transportation and the location problem solutions. Discussions are continued on the implications of the applications of the solutions, also the limitations of the models, and finally the suggestions for further works.

Chapter 1 begins with the introduction of local research activities on palm oil industry and some literature review on transportation and location issues were presented.

1.2 Palm Oil Research

Research about palm oil in Malaysia are mostly done by the Malaysian Palm oil Board (MPOB), independently or in cooperation with academic, industrial and other government research institutions. Although the setup of the Malaysian Massachusetts Institute of Technology (MIT) Biotechnology Partnership Programme (MMBPP) was to develop advanced technologies that command the future of biotechnology, but oil palm is one of its major functional areas. Apart from MPOB and MIT some of the other institutions that participated in the MMBPP were Forest Institute of Malaysia (FRIM), Palm Oil Research Institute of Malaysia (PORIM), Applied Agricultural Research (AAR), FELDA Agricultural Services Sdn. Bhd. and many others.

The research conducted by the MMBPP focused on two major areas. The first is the development and improvement methods for the cultivation of oil palm in tissue and suspended culture. Second, oil palm engineering produces biodegradable plastics. Most MPOB researches were focused on the seed breeding, pest and diseases control, oil extraction, design of new machines for mechanizing some field operations, product usage diversifications, and wastes and effluents management.

In 2004 the MPOB introduced 43 new technologies and products for commercialization in the industry and undertook 312 research projects. The new breakthroughs were mainly in developing cost-effective milling and refining techniques, improving yields, minimizing wastage and creating higher value-added palm-based products (edible and non-edible products) and palm-based biomass [64].

There was an advancement made in the R & D of the palm oil industry area classified by the MPOB as ‘Storage, Handling and Transportation of Palm Oil and Palm Oil Production’. This research area is probably the closest to this thesis where the discussion narrows to transportation. But a closer look shows ‘transportation’ referred to here was the mechanism of fruit handling and movement in the plantation area.

1.3 Literature Review (Transportation)

In 1941 Hitchcock first developed the transportation model. Dantzig (1963) then uses the simplex method on the transportation problem as the primal simplex transportation method. The modified distribution method is useful in finding the optimal solution for the transportation problem.

Charles et al. (1953) developed the stepping stone method, which provided an alternative way of determining the simplex method information.

Article on vehicle routing problem (VRP) was, originally posed by Dantzig et al. (1980). The VRP is commonly defined as the problem of designing optimal delivery or collection routes from one or several depots to a set of geographically scattered customers, under a variety of side conditions. Location-routing problems (LRPs) are VRPs in which the optimal depot locations and route design must be decided simultaneously.

Roy and Gelders (1980) solved a real life distribution problem of a liquid bottled product through a 3-stage logistic system; the stages of the system are plant-depot, depot-distributor and distributor-dealer. They modeled the customer allocation, depot location and transportation problem as a 0-1 integer programming model with the objective function of minimization of the fleet operating costs, the depot setup costs, and delivery costs subject to supply constraints, demand constraints, truck load capacity constraints, and driver hours constraints. The problem was solved optimally by branch and bound, and Langrangian relaxation.

Fisher and Jaikumar (1981) developed a generalized assignment for vehicle routing. They considered a problem where a multi-capacity vehicle fleet delivers products stored at a central depot to satisfy customer orders. The routing decision involves determining which of the demands will be satisfied by each vehicle and what route each vehicle will follow in servicing its assigned demand in order to minimize total delivery cost. They claim their heuristics will always find a feasible solution if one exists, something no other existing heuristics (until that time) can guarantee. Further, the heuristics can be easily adapted to accommodate many additional problem complexities.

Nambiar et al. (1989) solved a large-scale location-allocation problem in the Malaysian natural rubber industry using their own heuristic approaches. They formulated a minimization of overall costs objective function which consisted of travel and return costs of collecting latex from collecting stations to central factories, vehicle fixed charges, fixed charges for operating central factories and overtime costs for lorry crews. The problem was decomposed into a plant location part and a vehicle routing part.

Laporte et al. (1988) examined a class of asymmetrical multi-depot vehicle routing problems and location-routing problems, under capacity or maximum cost restrictions. The problem was formulated as a traveling salesman problem (TSP) in which it is required to visit all specific nodes exactly once and all non-specified nodes at most once. And, there exist capacity and maximum cost constraints on the vehicle routes; plus, all vehicles start and end their journey at a depot, visit a number of customers and return to the same depot.

Leung et al. (1990) develop an optimization-based approach for a point-to-point route planning that arises in many large-scale delivery systems, such as communication, rail, mail, and package delivery. In these settings, a firm, which must ship goods between many origin and destination pairs on a network, needs to specify a route for each origin-destination pair so as to minimize transportation costs. They developed a mixed multi-commodity flow formulation of the route planning problem, which contains sixteen million 0-1 variables, which is beyond the capacity of general IP code. The problem was decomposed into two smaller sub-problems, each amenable to solution by a combination of optimization and heuristic techniques. They adopted solution methods based on Langrangian relaxation for each sub-problem.

Saumis et al. (1991) considered a problem of preparing a minimum cost transportation plan by simultaneously solving the following two sub-problems: first the assignment of units available at a series of origins to satisfy demand at a series of destinations and second, the design of vehicle tours to transport these units, when the vehicles have to be brought back to their departure point. The original cost minimization mathematical model was constructed, which is converted into a relaxed total distance minimization, then finally decomposed into network problems, a full vehicle problem, and an empty vehicle problem. The problems were solved by tour construction and improvement procedures. This approach allows large problems to be solved quickly, and solutions to large test problems have been shown to be 1% or 2% from the optimum.

Achuthan et al. (1994) wrote an Integer Programming model to solve a vehicle routing problem (VRP) with the objective of distance minimization for the delivery of a single commodity from a centralized depot to a number of specified customer locations with known demands using a fleet of vehicles that a have common capacity and maximum distance restrictions. They introduced a new sub-tour elimination constraint and solved the problem optimally using the branch and bound method and used the CPLEX software to solve the relaxed sub-problems.

Tzeng et al. (1995) solved the problem of how to distribute and transport the imported coal to each of the power plants on time in the required amounts and at the required quality under conditions of stable and supply with least delay. They formulated a LP that minimizes the cost of transportation subject to supply constraints, demand constraints, vessel constraints and handling constraints of the ports. The model was solved to yield optimum results, which is then used as input to a decision support system that help manage the coal allocation, voyage scheduling, and dynamic fleet assignment.

Fisher et al. (1995) worked on a problem in which a fleet of homogeneous vehicles stationed at a central depot must be scheduled and routed to pickup and deliver a set of orders in truckload quantities. They defined schedule as a sequential list of the truckload orders to be carried by each vehicle, that is, where the bulk pickups and the delivery points are. They solved the problem by a network flow based heuristic, and claimed their algorithm consistently produces solutions within 1% of optimality.

A major oil company in the United States has dispatchers that are responsible for assigning itineraries to drivers to pickup crude products, using homogeneous capacity tank trucks, at designated locations for delivery to pipeline entry points. Bixby and Lee (1996) solved the problem to optimality with up to 2000 variables, applying branch and cut procedures on 0-1 IP (Integer Programming) formulations.

Brandao and Mercer (1996) used the tabu search heuristic to solve the multi-trip vehicle routing and scheduling in a real distribution problem, taking into account not only the constraints that are common to the basic routing problem, but also the following; during each day a vehicle can make more than one trip, customers delivery time windows, multi capacity vehicles, access to some customers is restricted to some vehicles, and drivers have maximum driving time with breaks.

Equi et al. (1996) modeled a combined transportation and scheduling in one problem where a product such as sugar cane, timber or mineral ore is transported from multi origin supply points to multi destination demand points or transshipment points using carriers that can be ships, trains or trucks. They defined a trip as a full-loaded vehicle travel from one origin to one destination. They solved the model optimally using Langrangean Decomposition.

In his paper entitled ‘Logistics costs and the location of the firm: a one-dimensional comparative static approach’, McCann (1996) argued that the total costs of distance are much greater than simply transportation costs. The reason is that transportation costs are only one component of total logistics costs, which also include inventory holding and purchasing costs, and these total logistics costs can be shown to be directly related to haulage distance. Further, he showed that the interregional mobility of a firm will depend on the price of the goods being shipped.

Jayamaran (1998) formulated a mixed Integer programming model that looked into the relationship between inventory, location of facilities and transportation issues in a distribution network design. The formulation involves minimizing the cost of warehouse and plants location, inventory related costs and transportation costs of products from open plants to open warehouses and costs to deliver the products from warehouses to customer outlets.

Kim and Pardalos (1999) considered the fixed charge network flow problem, which has many practical applications including transportation, network design, communication, and product scheduling. They transformed the original discontinuous piecewise linear formulation into a 0-1 mixed IP problem to solve very large problem of up to 202 nodes and 10,200 arcs using a heuristics called dynamic slope scaling procedure that generate solutions within 0% to 0.65% of optimality in all cases.

Wang and Regan (2000) describe a solution method for a multiple travel salesman problem with time window constraints to develop vehicle assignment for a local truckload pickup and delivery. The integer 0-1 model was developed with the objective to minimize total transportation cost with fleet size fixed, vehicles to pick up and leave each load at most once, vehicles departs from a load only if it serves the load first, and time window requirements. The model was run to optimality using CPLEX version 5.0

Budenbender et al. (2000) worked on a network design problem for letter mail transportation in Germany with the following characteristics; freight has to be transported between large number of origins and destinations, to consolidate it is first shipped to a terminal where it is reloaded and then shipped to its destination. The task is to decide which terminals have to be used and how the freight is transported among terminals. They modeled the problem as a capacitated warehouse location problem with side constraints using mixed IP and solved by a hybrid tabu search / branch-and-bound algorithm.

Chao (2000) studied the truck and trailer routing problem, which is a variant of the vehicle routing problem. The problem looked into some real-life applications in which fleet of *mk* trucks and *ml* trailers (*mk* > *ml*) services a set of customers. There are three types of routes in a solution to the problem: (1) a pure truck route traveled by a truck alone, (2) a pure vehicle route without any sub-tours traveled by a complete vehicle, and (3) a complete route consisting of a main tour traveled by a complete vehicle, and one or more sub-tours traveled by a truck alone. A sub-tour begins and finishes at a customer on the main tour where the truck uncouples, parks, and re-couples its pulling trailer and continues to service the remaining customers on the sub-tour. The objective is to minimize the total distance traveled, or total cost incurred by the fleet. He solved the problem by tabu search and deterministic annealing.

Irnich (2000) introduced a special kind of pickup and delivery problem, called 'multi-depot pickup and delivery problem with a single hub and heterogeneous vehicles'. All request have to be pickup at or delivered to one central location which has the function of a hub or consolidation point. In hub transportation network routes between customers and the hub are often short, involve only one or very few customers. The problem primarily considers the assignment of transportation request to routes. The author concludes that many problems in transportation logistics can be modeled and solved similarly whenever routes can be enumerated and the temporal aspects of transportation requests are important.

Diaz and Perez (2000) applied the simulation optimization approach proposed by Vashi and Bienstock (1995) to solve the sugar cane transportation problem in Cuba that involved thousands of workers, dozens of cutting machines, hundreds of tractors and several hundreds of truck and trailers.

Li and Shi (2000) formulated a dynamic transportation model with multiple criteria and multiple constraint levels (DMC2) using the framework of multiple criteria and multiple constraints (MC2) LP. An algorithm is developed to solve such DMC2 transportation problems. In this algorithm, dynamic programming ideology is adopted to find the optimal sub-policies and optimal policy for a given DMC2 transportation problem. Then the MC2-simplex method is applied to locate the set of all potential solutions over possible changes of the objective coefficient parameter and the supply and demand parameter for the DMC2 transportation problem.

Cheung and Hang (2001) studied a routing problem for a land transportation of air-cargo freight forwarders in Hong Kong, which allows time windows, backhauls, heterogeneous vehicles, multiple trips per vehicle and penalty for early arrival at customer sites. They formulated an IP to minimize the traveling costs and waiting costs subject to demand constraints, continuous flow of the vehicle constraints, time window constrains, and capacity constraints. They developed two optimization-based heuristics to solve the problem, and using real data they showed that the model produce quality solutions quickly and are flexible in incorporating complex constraints.

The classical vehicle routing problem (VRP) consists of a set of customers with known locations and demands, and a set of vehicles with a limited capacity, which are to service the customers from a central location referred to as depot. The routing problem is to service all the customers without overloading the truck, while minimizing the total distance traveled and using minimum number of trucks. Thangiah and Salhi (2001) studied a multi depot vehicle routing problem with vehicles starting from different depots, which is an extension of the classical VRP. They solved the problem by a generalized clustering method based on a genetic algorithm, called genetic clustering.

Doerner et al. (2001) solved a problem for a logistics service provider to satisfy a set of transportation requests between distribution centers. Each order is characterized by its size, it fills a truck completely, and its time window for pickup and delivery. Since consolidation is not an option, each order is transported directly from its source to its destination. The available fleet is distributed over the distribution centers, and each vehicle is constrained by a maximum tour length restrictions. The minimum fleet-size and minimum distance problem was solved by ant colony optimization.

Wu et al. (2002) proposed a decomposition-based method for solving the location-routing problem (LRP) with multiple depot, multiple fleet types, and limited number of vehicles for each different vehicle type. Like in any LRP it is assumed that the number, location, and demand of customers, the number, and location of all potential depots, as well as the fleet type and size are given. The distribution and routing plan must be designed so that; the demand of each customer can be satisfied, each customer is served by exactly one vehicle, the total demand on each route is less than or equal to the capacity of the vehicle assigned to that route, and each route begins and ends at the same depot. Decision must be made on the location for factories/warehouse/distribution centers DC, referred as depots. Also, the allocation of customers to each service area must be decided. Transportation must be planned to connect customers, raw materials, plants, warehouses, and channel members. They formulated the mathematical problem to solve the above decisions simultaneously with the objective function to minimize the depot setup cost, delivery cost and the dispatching cost for the vehicles assigned subject to the following constraints (1) each customer assigned on a single route (2) vehicle capacity (3) sub-tour not allowed (4) flow conservation (5) each route served at most once (6) capacity for DC (distribution center) (7) customer assigned to DC if there is a route from that DC through that customer. This problem was solved using simulated annealing.

Gronalt et al. (2002) studied pickup and delivery of truckloads under time window constraints. A logistic service provider studied, accepts orders from customers requiring shipments between two locations, and serves the orders from a number of distribution centers. Thus, shipments occur between the pickup location of an order and the closest distribution center, between distribution centers and between a distribution center and the delivery location of an order. The problem was formulated as a mix integer program with the objective of minimizing empty vehicle movement, and solved using a heuristic known as saving algorithm proposed by Clark and Wright (1963).

Gigler et al. (2002) applied dynamic programming (DP) in the supply chain of agricultural commodities, or what they called as agri chains. They applied DP methodology specifically in a case of the supply chain of willow biomass fuel to an energy plant. Included in the DP approach not only transportation but also various stages of handling (harvesting) and processing (natural drying) of the biomass fuel.